

Migration

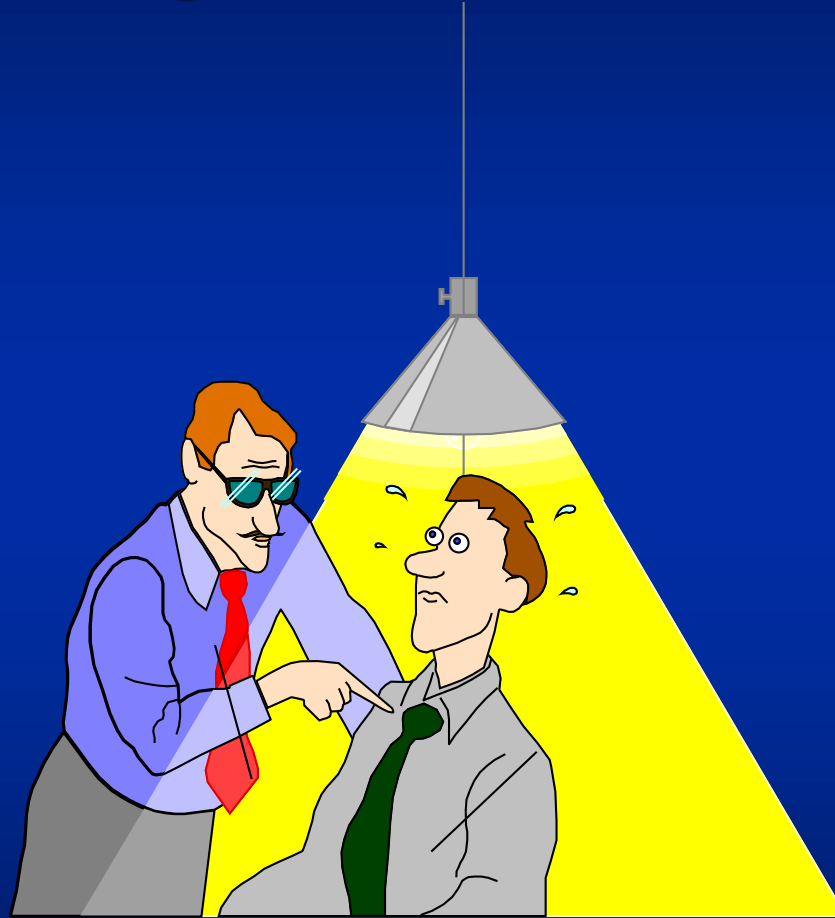
At the end of this Session, you will be able to:

- Define the term 'migration' and describe why we need to migrate seismic data.
- Define the term 'diffraction energy'.
- Describe how the application of migration can affect dipping events and diffraction energy.
- To introduce the importance of the velocity field in the process of migration.
- Define the terms 'under migration' and 'over migration' in relation to a migration velocity field.
- Describe at least 3 ways in which a stacking velocity field may be manipulated to improve its suitability for the post-stack migration.
- Describe at least 2 reasons why scaling of stacking velocity fields may be required prior to their use in migration.
- Define the term 'migration smile'.

The Routemap

- What is, and why perform, migration ?
- What types of migration are there ?
- What does the choice of migration type depend on ?
- What velocities do we use for migration ?

What is Migration and why do we need to Migrate seismic data ?



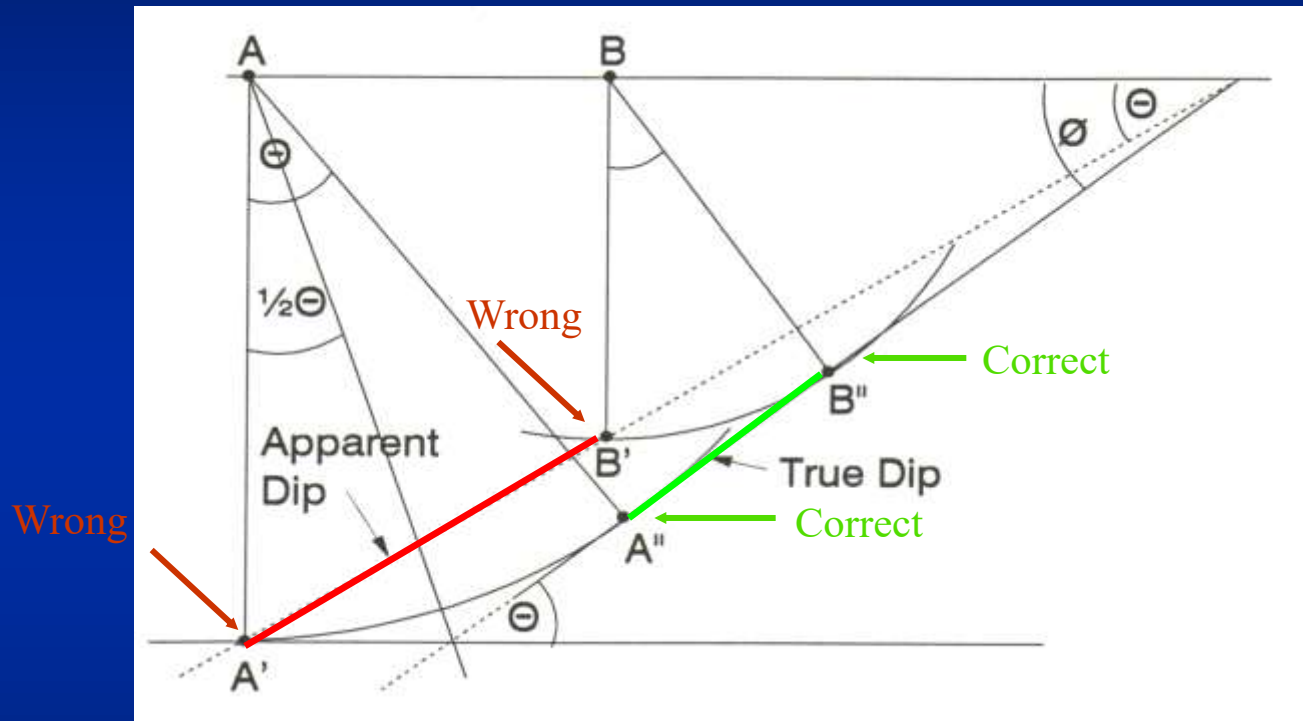
What is Migration ?

- Migration is a process which attempts to correct the distortions of the geological structure inherent in the seismic section
- Migration re-distributes energy in the seismic section to better image the true geological structures

Why Migrate ?

- Rearrange seismic data so that reflection events may be displayed at their true position in both space and time.
 - laterally in up-dip direction
 - upward in time
- Collapse diffractions back to their point of origin
- Improve lateral resolution - collapse Fresnel zone
- To obtain more accurate velocity information (when performed pre-stack)
- For more accurate 'depth' section

Apparent Dip

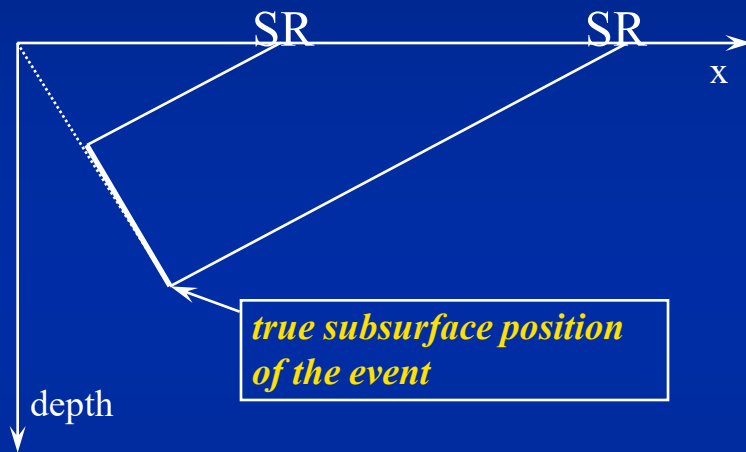


A zero offset stack section gives a false picture of dipping reflectors as events A'' and B'' are plotted at trace positions A' and B' respectively.

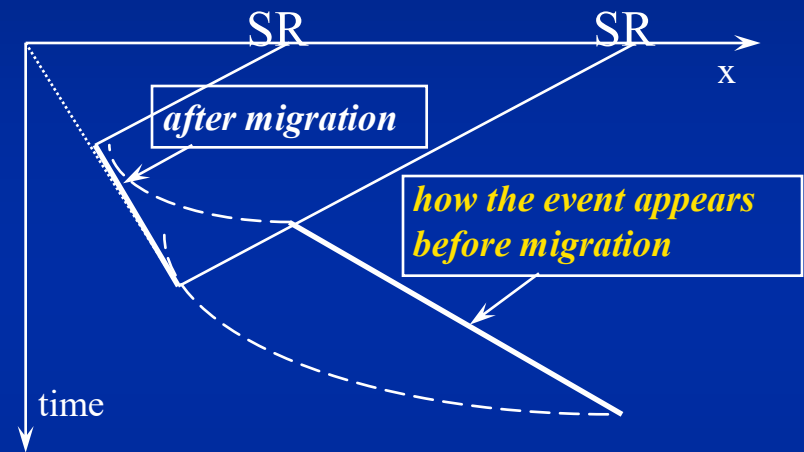
The apparent dip of an event on a zero offset stack section is **less than** the true dip of the event.

Recap

Depth section



Time section



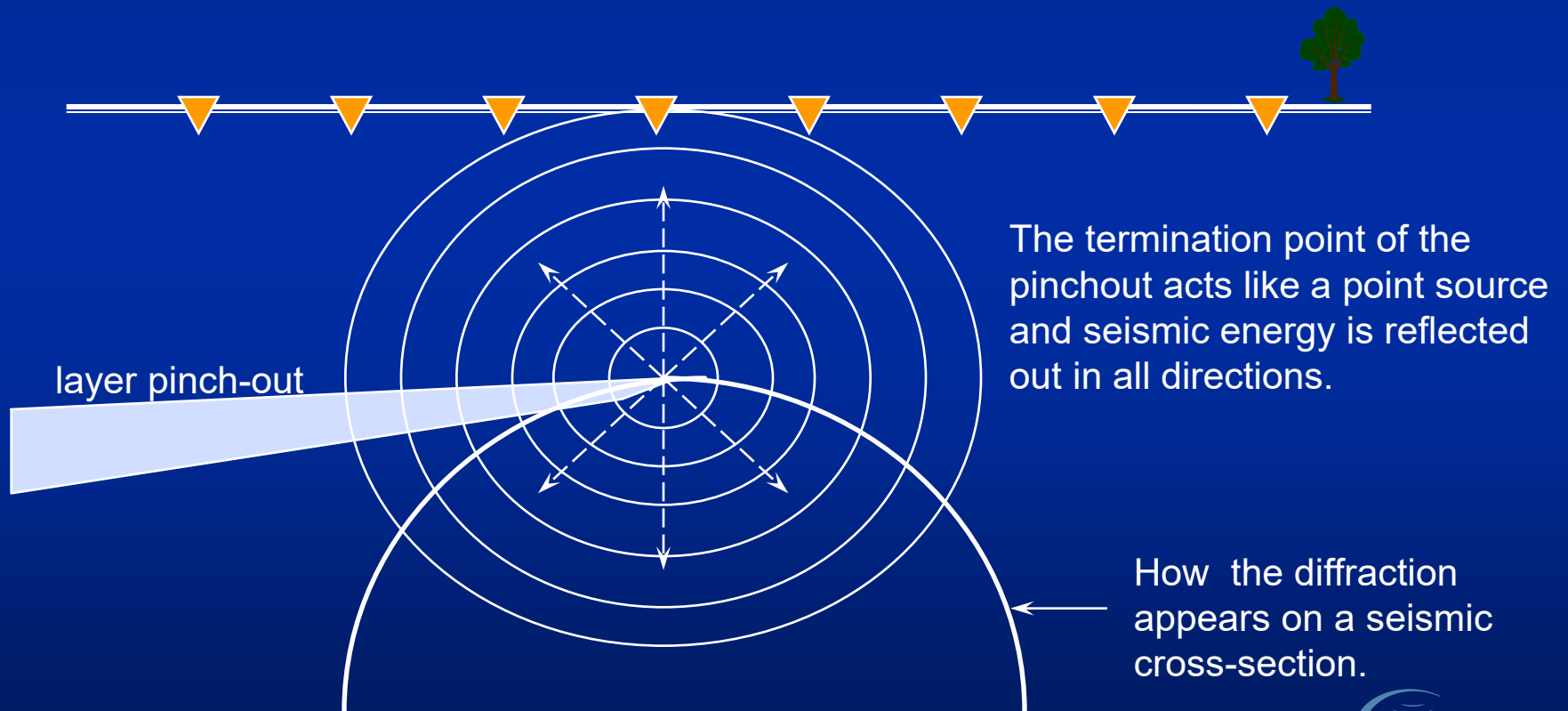
This is a constant velocity case

- > Migration moves events updip
- > Migration steepens events
- > Migration shortens events

Diffractions

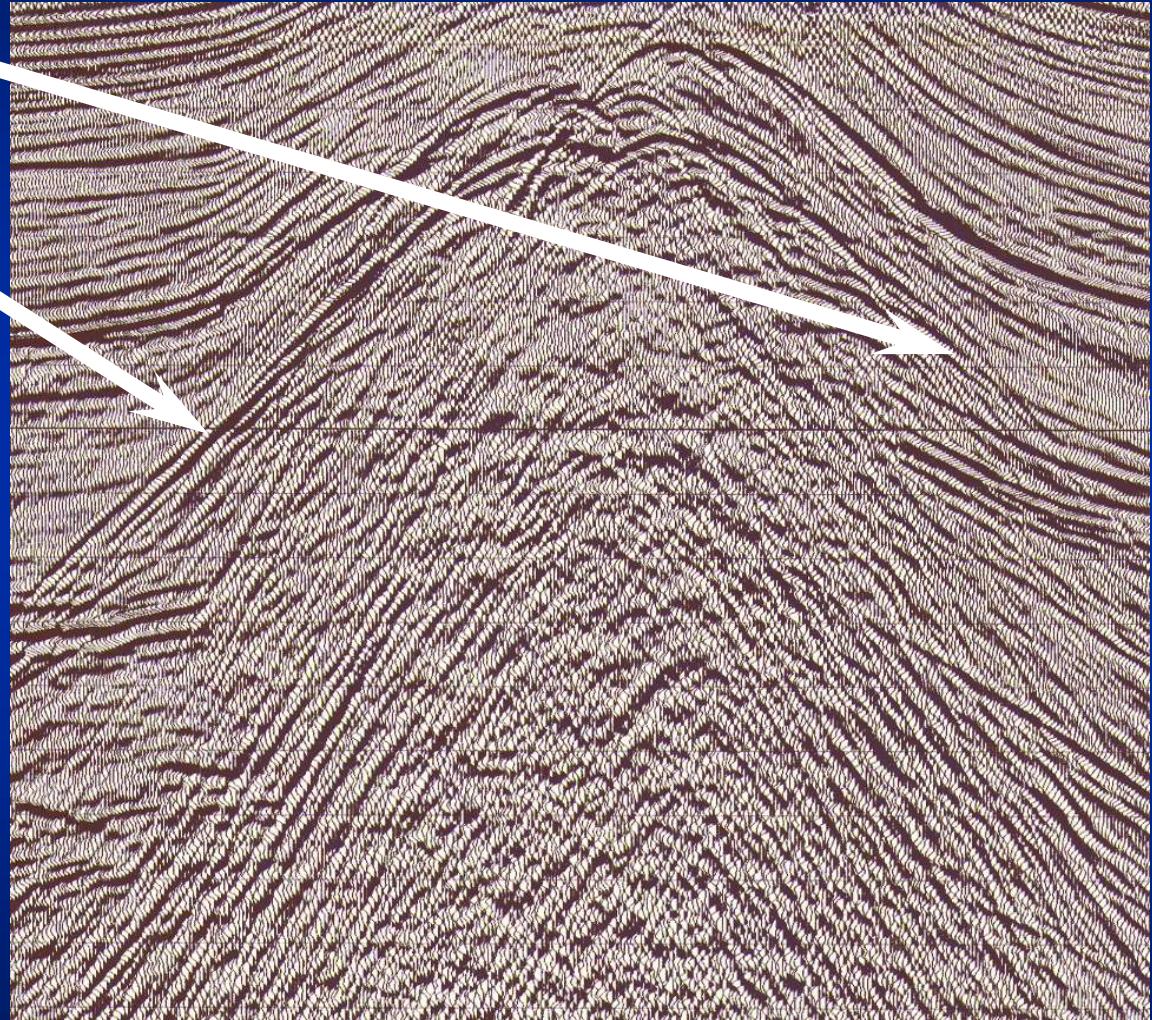
When wave energy strikes discontinuities in the subsurface, diffraction occurs and the seismic waves are bent around the discontinuity.

This happens at layer pinchouts, faults etc.



Data Example

Diffractions

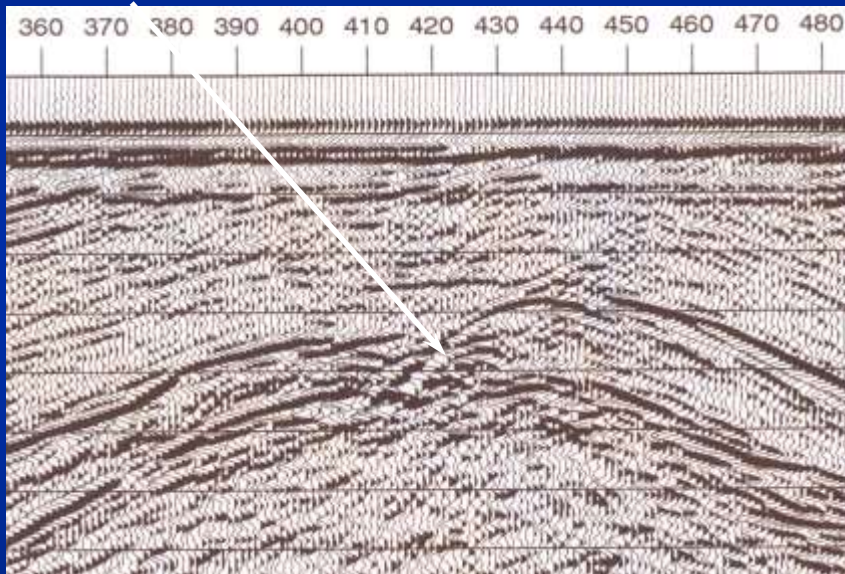


Diffracted energy appears very similar to that reflected from an anticline.

Diffracted energy **IS** useful

Velocity Errors

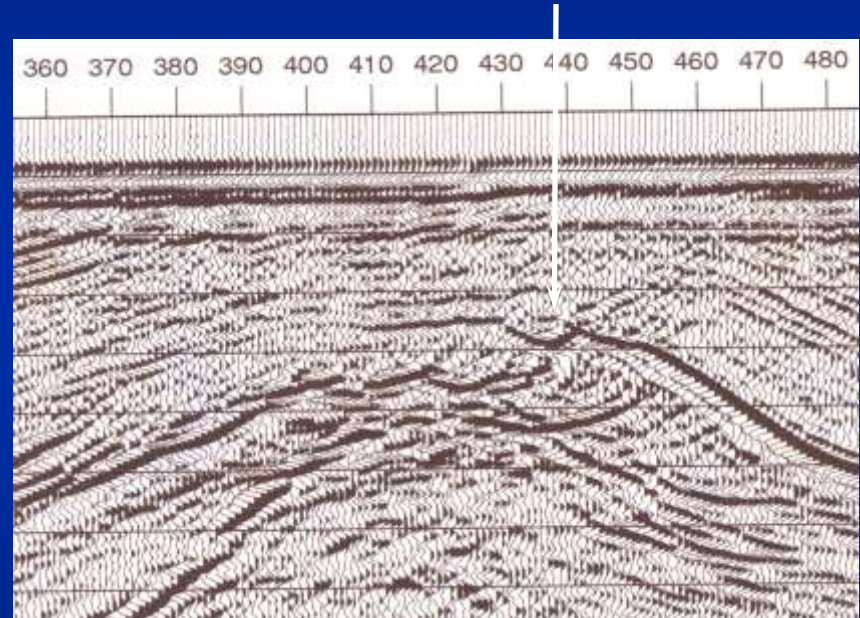
Diffractions not collapsed



Undermigrated

Velocities too low

Turned into a smile

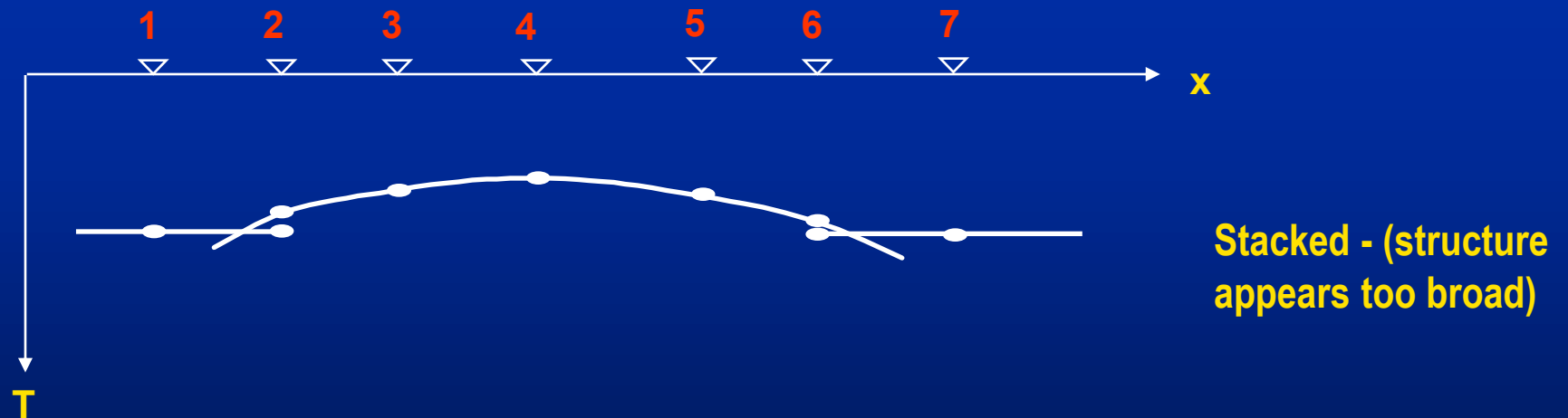
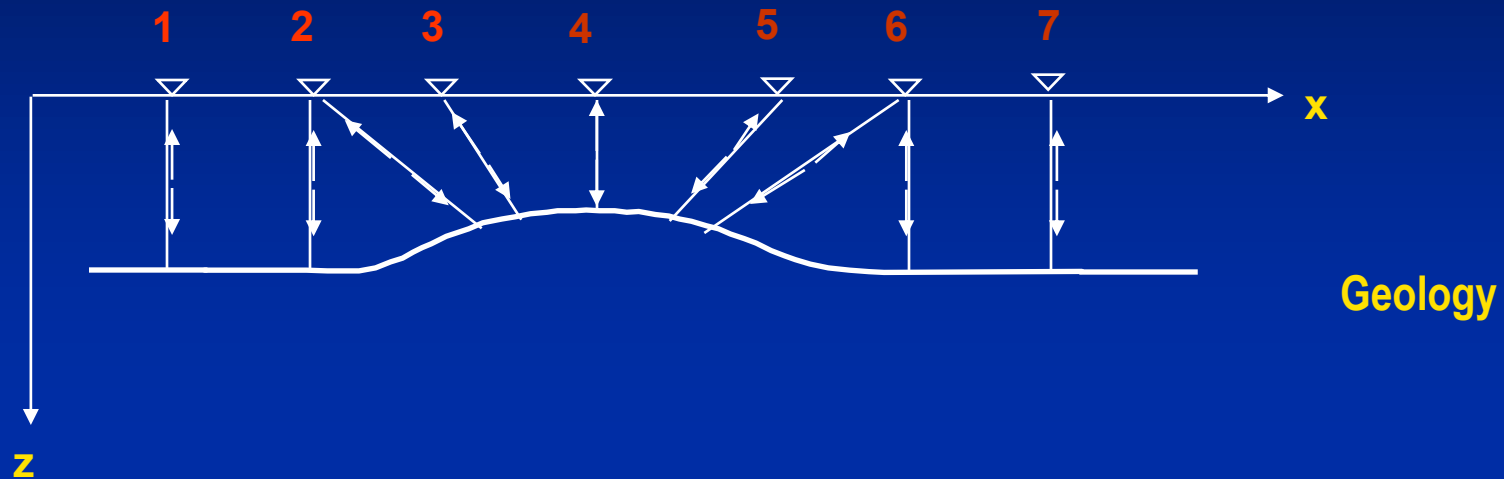


Overmigrated

Velocities too high

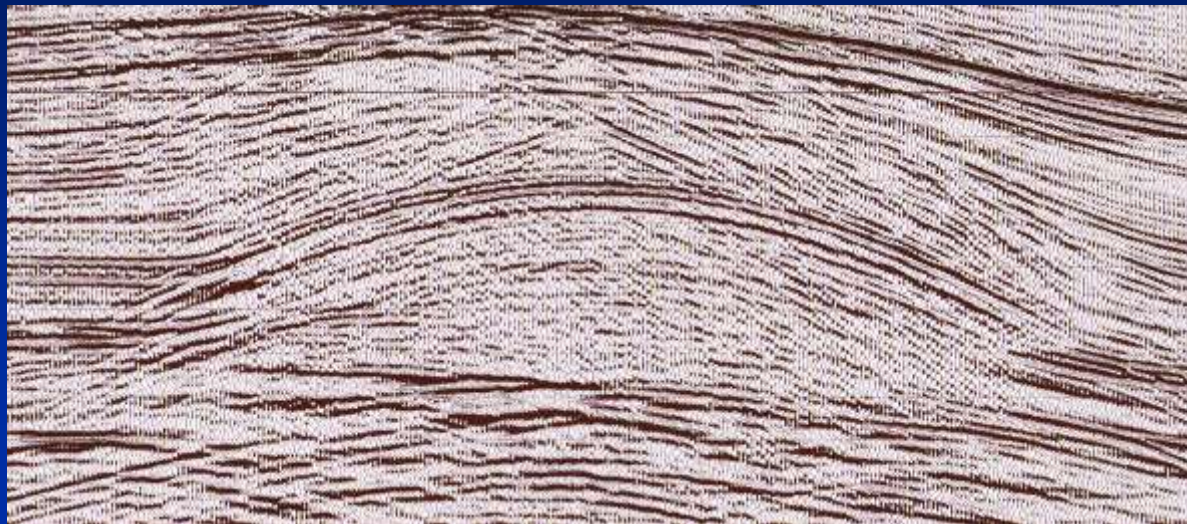
Important Structural Features

Anticline

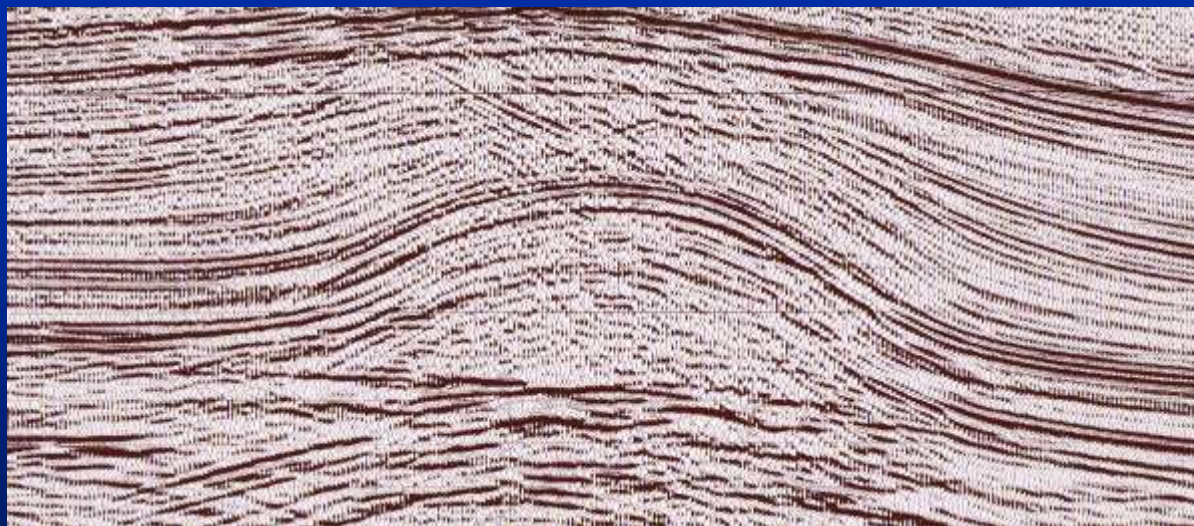


Anticline - Data Example

STACK



Geology

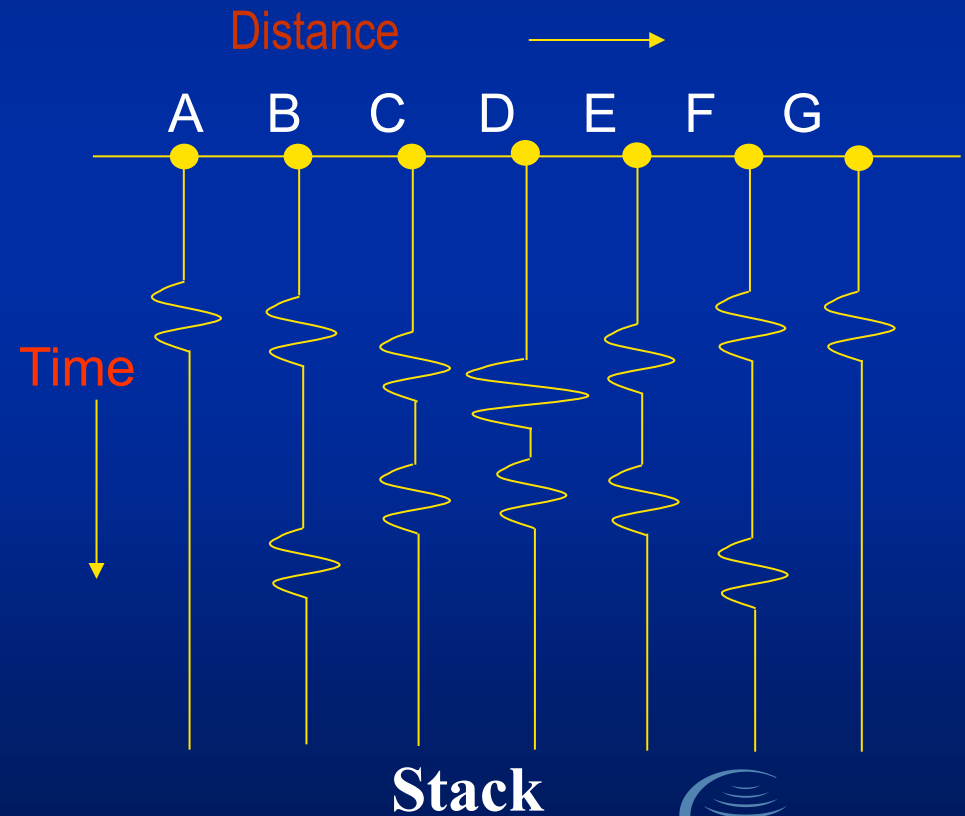
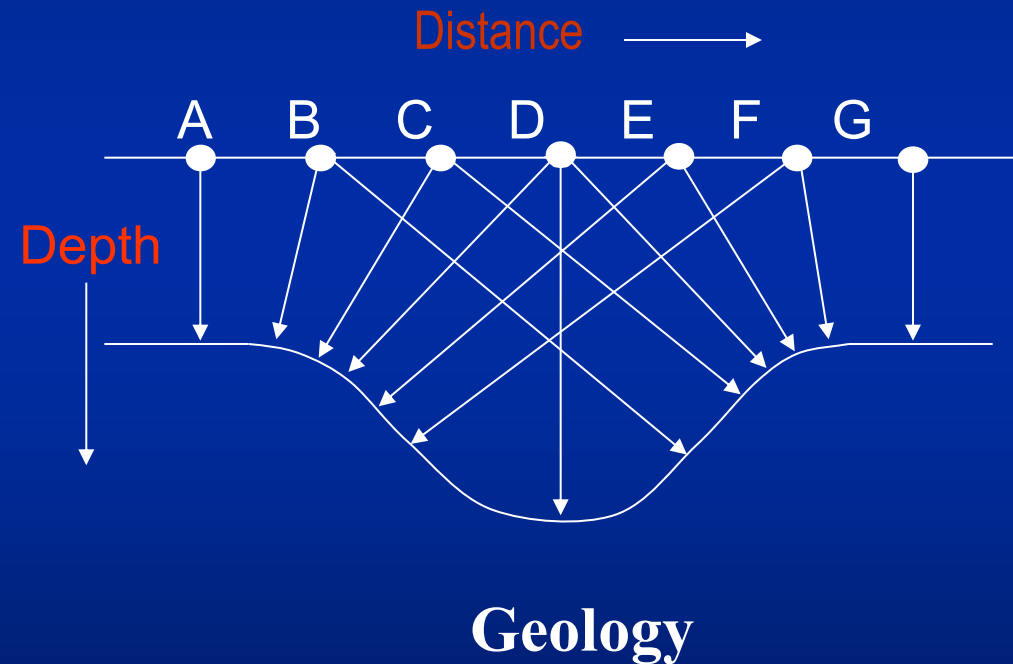


MIGRATION

Important Structural Features

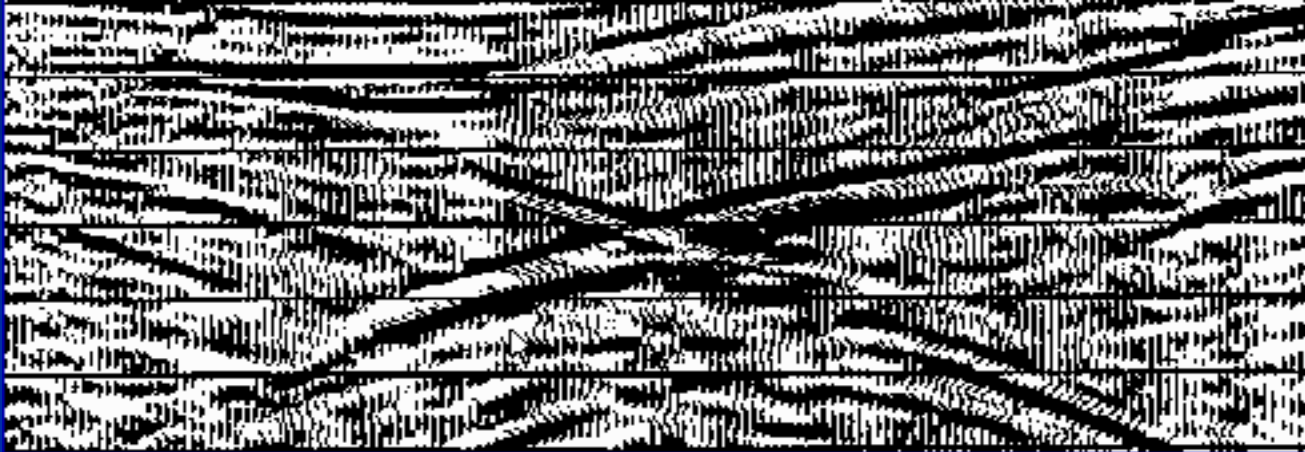
Syncline

- Left, below, shows true zero-offset ray paths for coincident sources and receivers at surface points A through G to a synclinal reflector. The curvature of the reflecting horizon is such that there are multiple perpendicular ray paths from surface positions B through F. On the right is shown how a syncline will appear on a stacked section

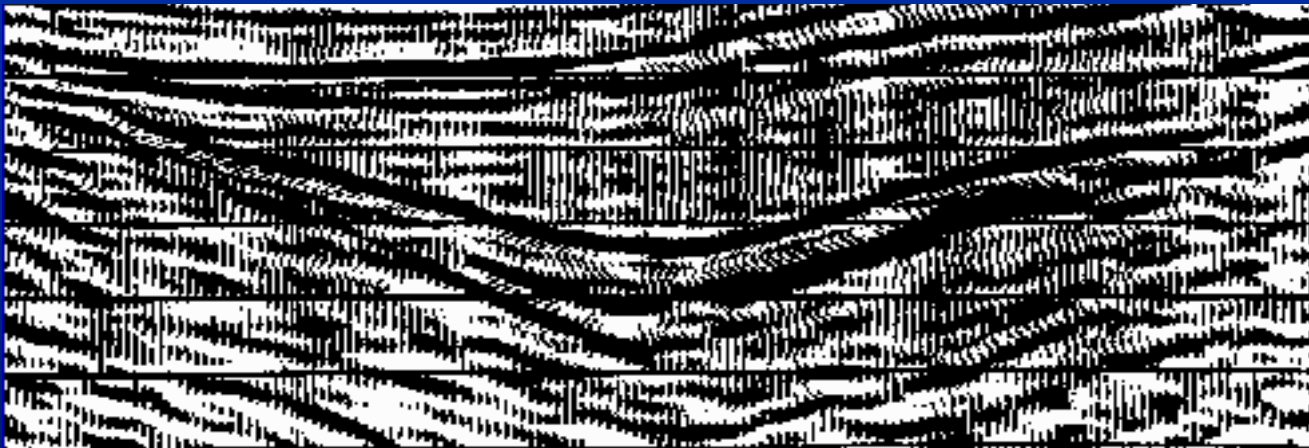


Syncline - Data Example

STACK
(showing
“bow-tie”
effect)



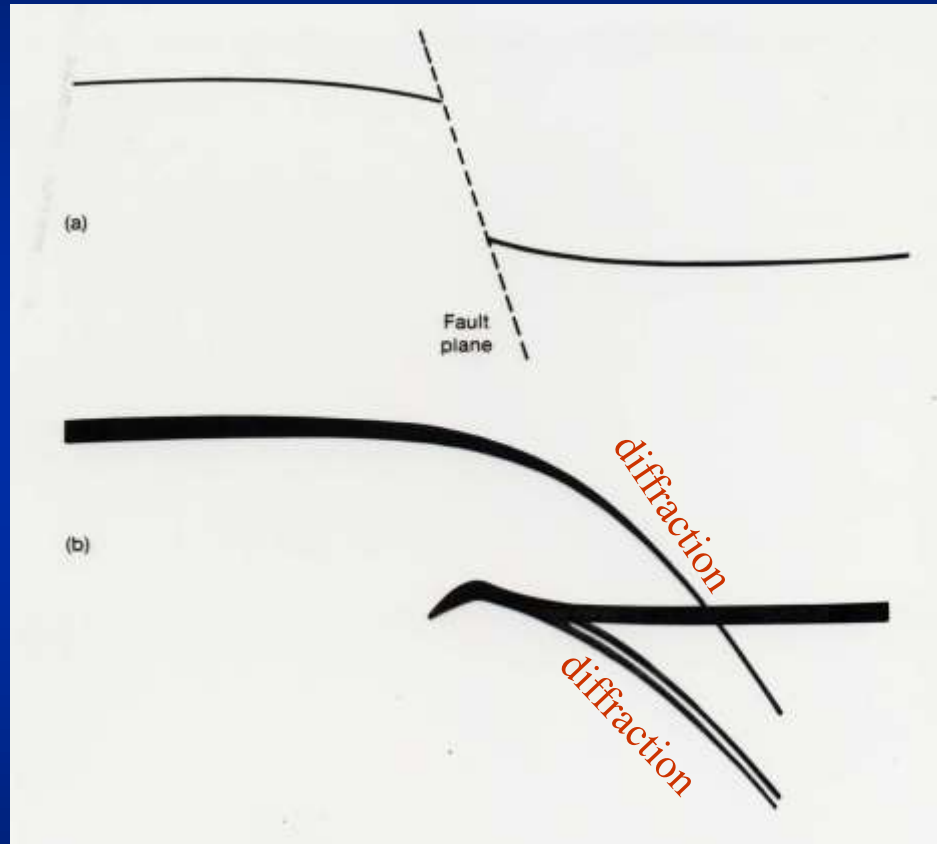
Geology



MIGRATION

Important Structural Features

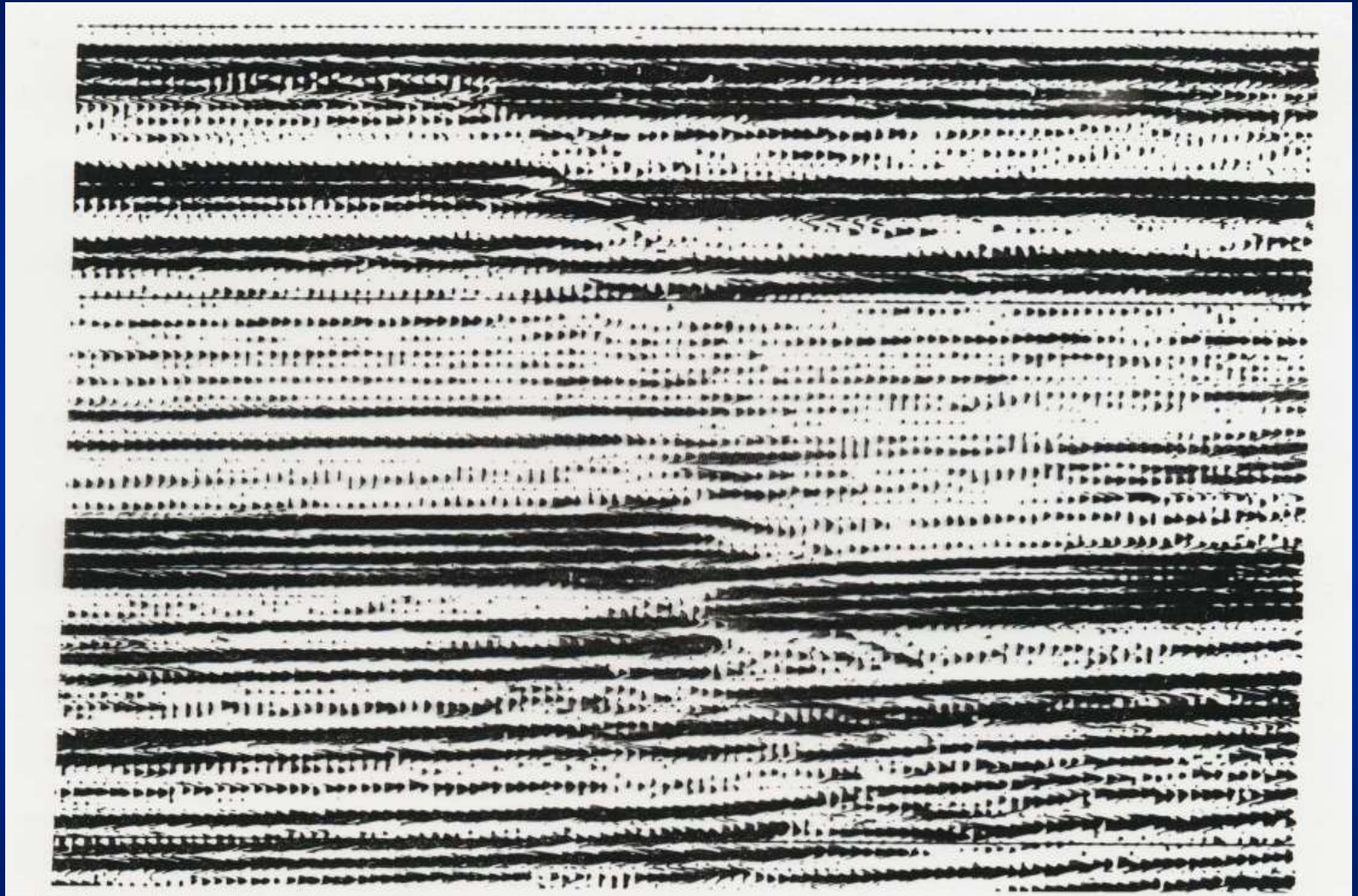
Fault



Geology

Stack

Fault - Stacked Data Example



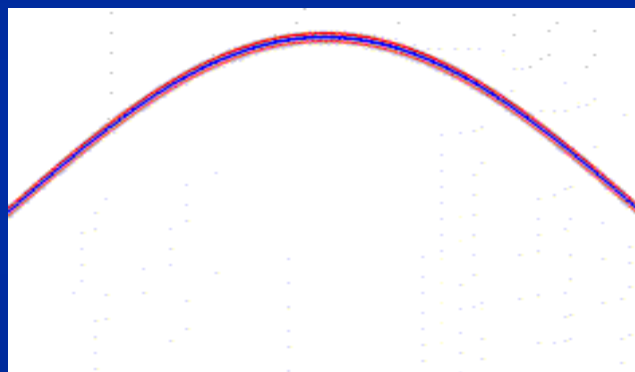
DP START Oslo
2004

 WesternGeco

Importance of Velocity

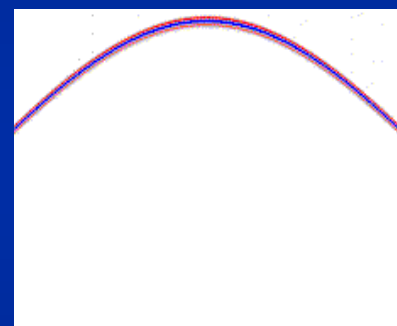
A local high- **Anticline** appears wider on the stacked section. The apparent width depends on the dips on each flank - the steeper the dips the wider the structure on the stacked section.

stacked section



Anticline

migrated section

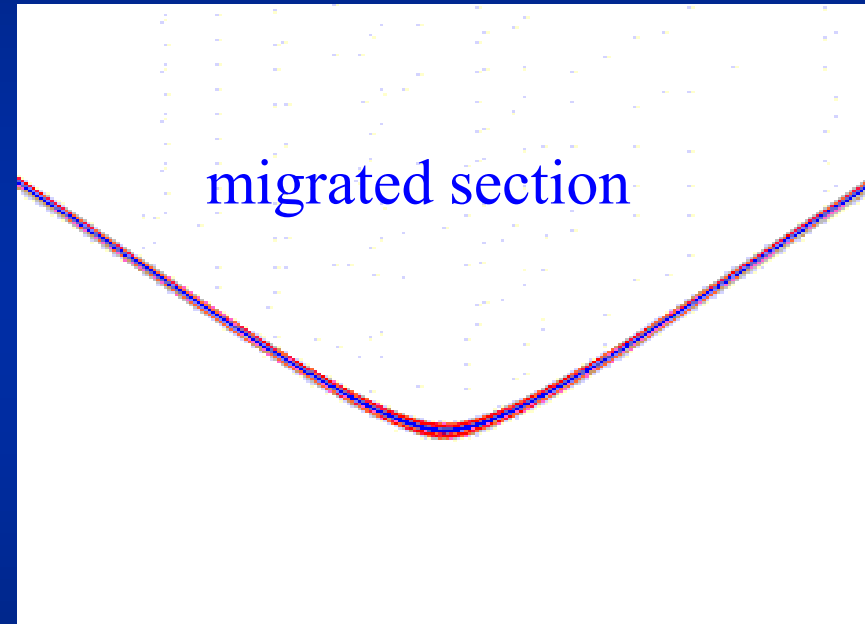
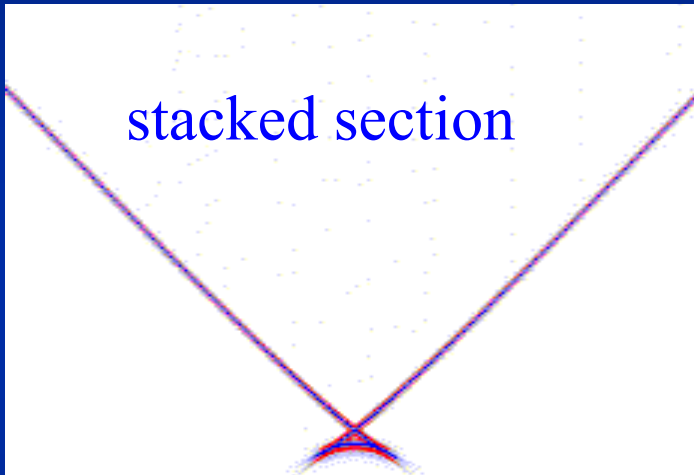


If our velocities are incorrect, the final migrated structure may be narrower or wider than the true structure - this could lead to the wrong estimate of any oil or gas reserves under this “high”.

Importance of Velocity

A local depression - **Syncline** appears narrower on the stacked section

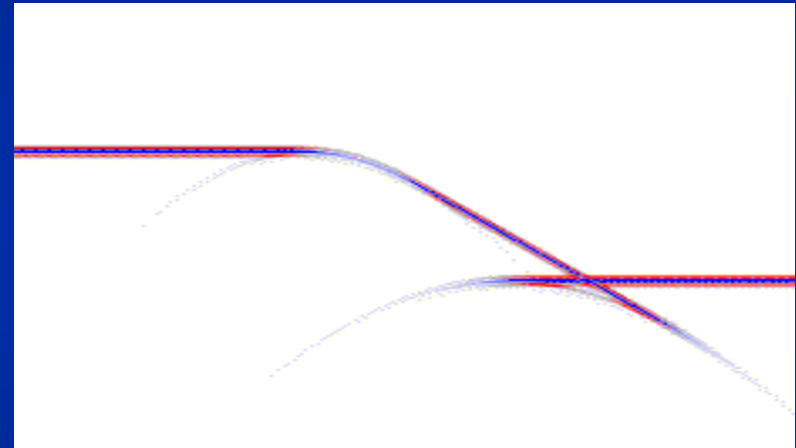
Syncline



If the velocities are too high, the **syncline** will be wider than it should be after migration. Velocities that are too low will “under migrate” the structure, leaving it too narrow.

Importance of velocity

A perfectly horizontal event with a fault plane.



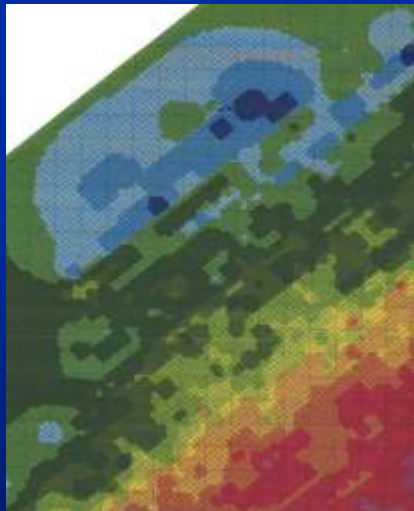
If the velocity field is incorrect, the fault plane will not “move” to the correct place and the diffraction curves from the “corners” of the structure will not focus correctly

Migration Velocity Field

Modifications must be made to the stacking velocity field so that it can be used for Migration.

Smoothing

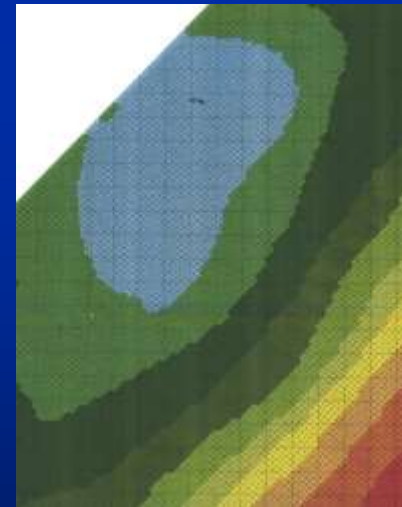
Time migration algorithms cannot handle strong lateral velocity variations



Stacking velocity field



Filtering in time / horizon
consistent manner

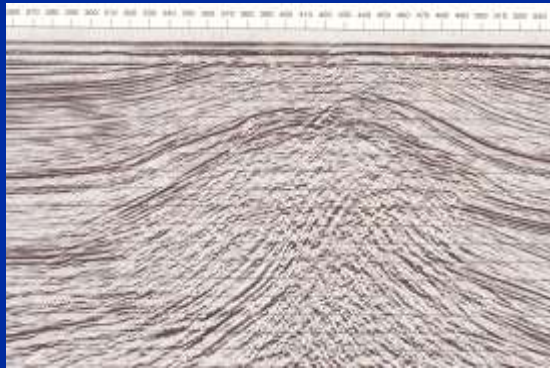


Smoothed velocity field

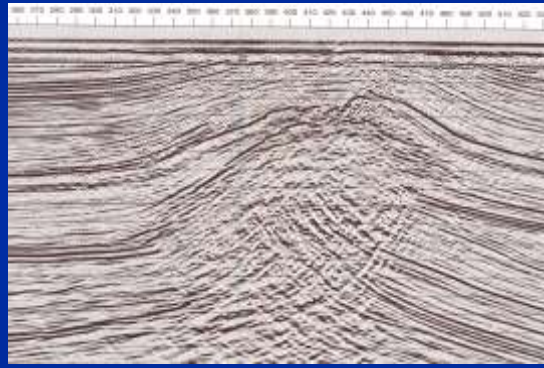
Migration Velocity Field

Scaling

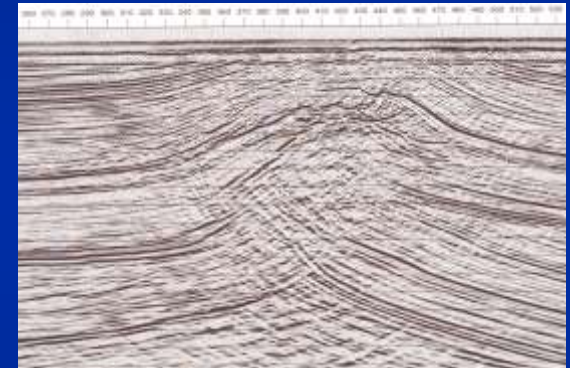
Trial migrations are conducted using varying percentages of the stacking velocity field



*80% of stacking
velocities*



*100% of stacking
velocities*



*120% of stacking
velocities*

Conversion to interval velocities

Stacking velocities must be converted to interval velocities to be of use to most migration algorithms. These conversions are done internally.

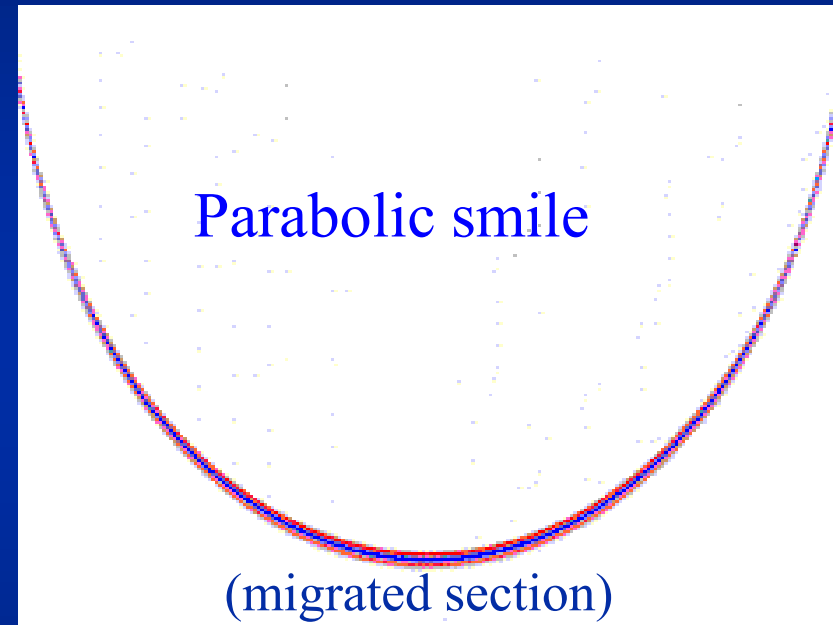
A strange structure

If we had an inverted perfectly parabolic event in the ground, with its centre on our CDP, we would see only one point on our stacked section

A glitch or a spike



(stacked section)



If we have a single “point” of energy in our stacked section that does not correspond to a “real event” (e.g a spike), this will migrate into a parabolic “smile” on our migrated section.

Recap

Why do we need to migrate seismic data ?

- re-arrange events to true subsurface positions
- dipping events will shorten, steepen and move updip
- diffraction energy will be collapsed
- amount of under and over migration will depend on the velocity

At the end of this Session, you will be able to:

- Define the 'imaging principle' and describe how it is related to the concept of 'exploding reflectors'.
- Define the principle of 'downward continuation' and describe how it is used in the migration process.
- Define the term 'migration algorithm'.
- Define the 3 main categories of migration technique namely, 'Finite-Difference', 'Integral' and 'Transform' methods
- Name at least 4 algorithms based on these techniques.
- Define the terms 'pre-stack migration' and 'post-stack migration'.
- Define the terms 'time migration' and 'depth migration'.

Types of Migration

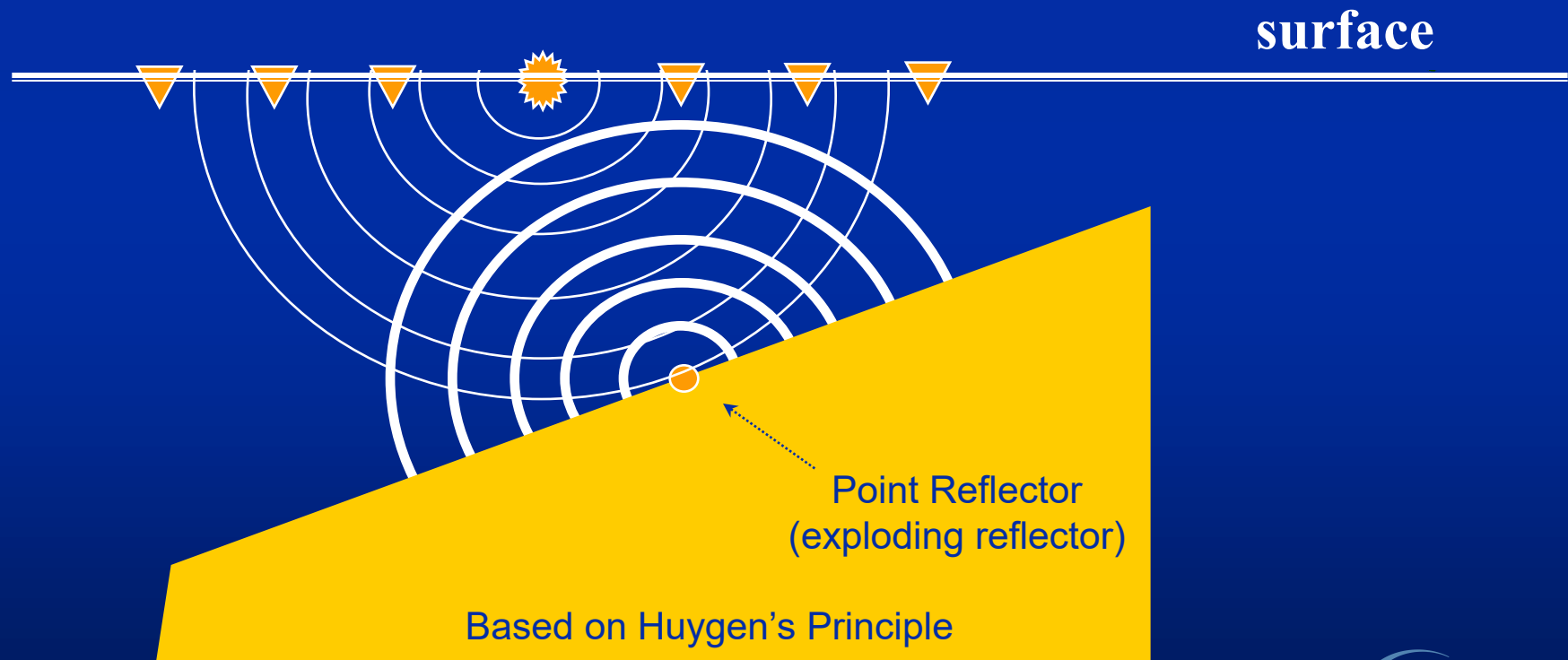


- Principles
- Techniques / Algorithms
- Time or Depth?
- Pre-Stack or Post Stack?
- 2D or 3D?

Important Principles

Exploding Reflectors

Each point on a reflector can be considered as a secondary source of energy. If we could measure the shape of the wave front at $t=0$ (i.e. at the reflector surface), since no propagation has occurred at this time then the wave front shape must be the same as the reflector shape that generated the wave front. This is the **IMAGING principle**.



Important Principles

Downward Continuation

The imaging is achieved by extrapolating the wave-field back in depth, from the surface to the exploding reflector where, $t = 0$

Downward continuation is performed at regular depth or time intervals until all reflectors are 'imaged'.

Migration Techniques

Most modern migration techniques are based on the scalar wave equation, which 'relates the spatial and time dependence of a disturbance which can propagate as a wave'*

* R.E.Sheriff

In rectangular co-ordinates x, y and z

$$\frac{\partial^2 \psi}{\partial x^2} + \frac{\partial^2 \psi}{\partial y^2} + \frac{\partial^2 \psi}{\partial z^2} = \frac{1}{V^2} \psi$$

Where ψ represents wave displacement (pressure, rotation etc) and V the velocity of the wave

Migration Techniques

Three main categories

(most of these use the principle of downward continuation and exploding reflector model)

- **Finite-Difference Methods**- based on differential solutions to the scalar wave equation
- **Integral Methods**- integral solution to the scalar wave equation. Based on summing the seismic amplitudes along a diffraction hyperbola whose curvature is governed by the medium velocity
- **Transform Methods**- involving co-ordinate transformation into mainly F-K domain

Migration Techniques

- **Finite-Difference Methods-**

generally used when vertical velocity variations exist with gentle lateral velocity variations and dips of the events are moderate.

- **Integral Methods-** Used mainly when data exhibits high dips. Lateral velocity variations can still be a problem. **Kirchhoff migration** is an example. Uses RMS velocities instead of interval velocities.

- **Transform Methods-** usually implemented in F-K domain. Examples are: **Phase-shift** and **Stolt migrations**. These are relatively cheap to run.

Important Migration Algorithms

Name	Method	Comments
Finite-Difference	Downward continuation migrates in steps from receivers downwards	can only handle dips up to 60 degrees can handle minor lateral velocity variations can handle low S/N
Kirchhoff	based on diffraction summation. Uses Huygen's principle	can handle dips up to 90 degrees cannot handle strong lateral velocity variations poor when low S/N
F-K (Stolt, Phase-Shift)	converts to frequency- wave-number domain before migrating. Stolt can be used to perform residual migration	can handle dips up to 90 degrees generally poor at handling lateral velocity variations. poor when low S/N
F-X (Omega-X)	type of Finite-Difference migration in the frequency domain	can handle dips up to 90 degrees can handle moderate velocity variations. each frequency can be processed separately. poor when low S/N

Time or Depth Migration?



Time or Depth Migration ?

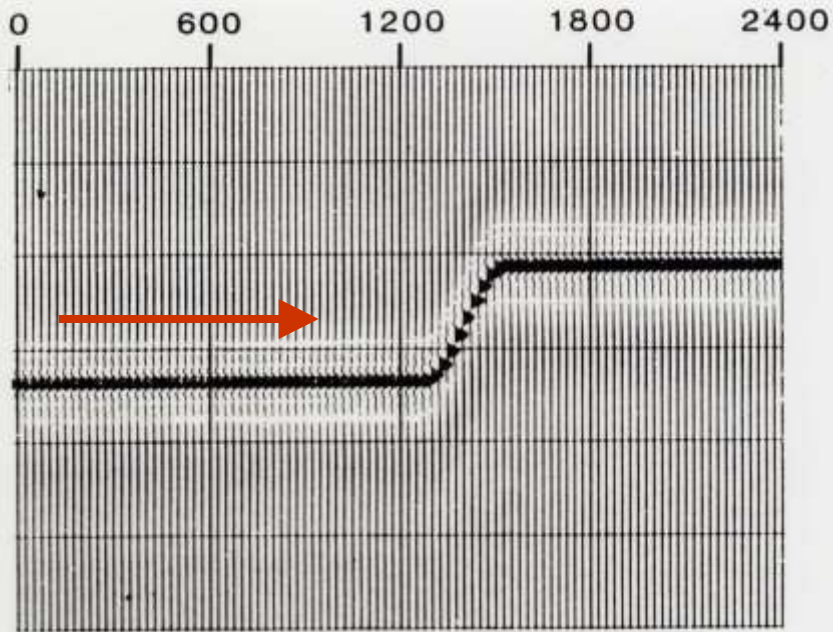
Ideally we want a depth section from a stacked section. The best way to achieve this is to do Depth Migration. However, time migration is considered adequate for most surveys. Depth Migration is too time consuming and expensive to be widely used

- interpreters prefer to evaluate the velocity of migrated section by comparing with un-migrated data. More common is to migrate with varying percentages and then compare the results.
- Stacking velocities are accurate for stacking and may not be true velocities. Much work is required to build a velocity model for depth migration.

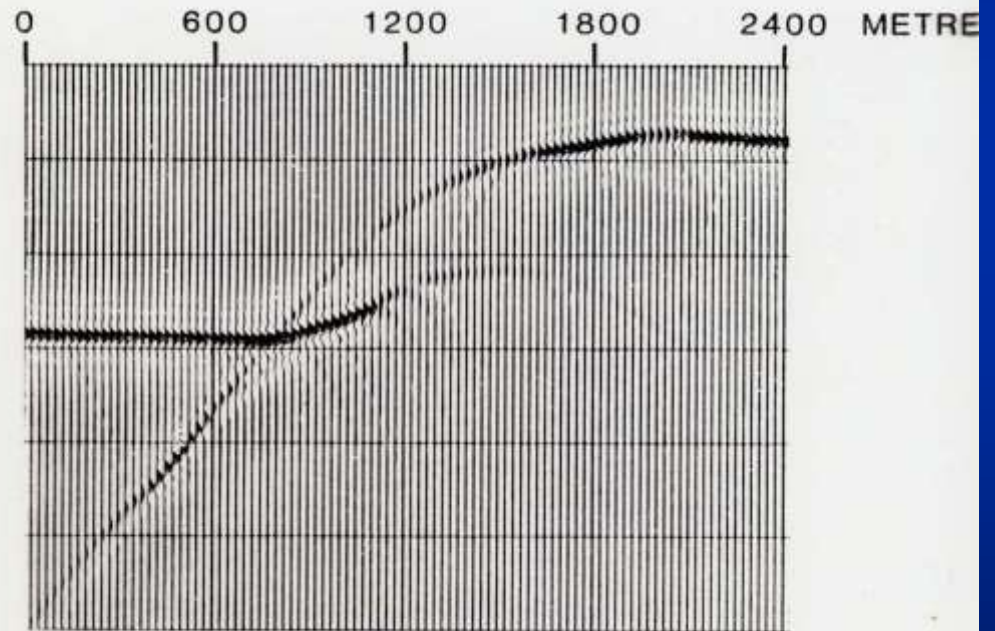
However,

- when lateral variations in velocity are severe, Depth Migration is needed as the ray-path bending takes place due to strong velocity contrasts. In such cases, Time Migration is not adequate.

Time or Depth Migration

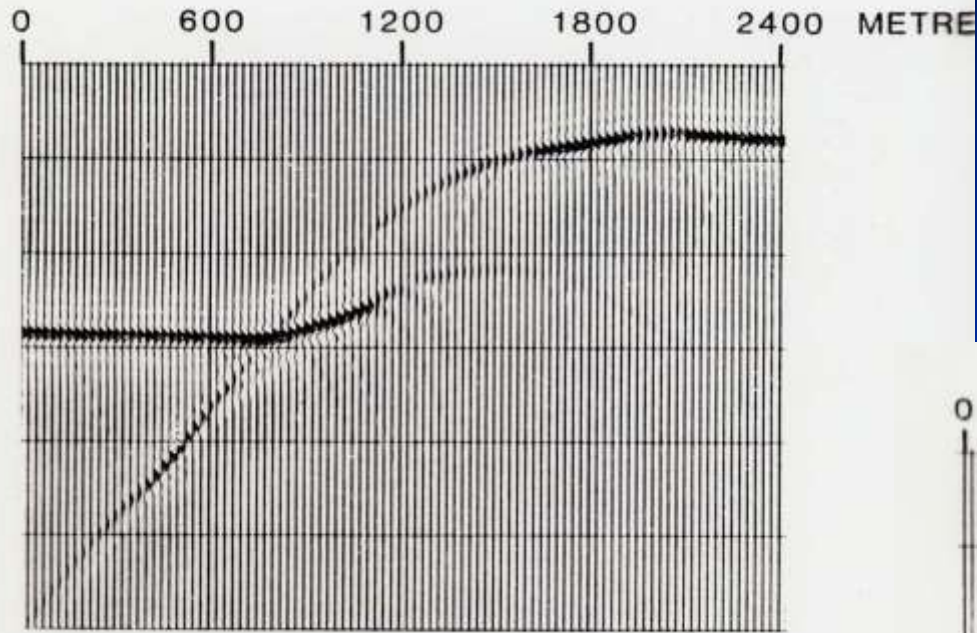


Model

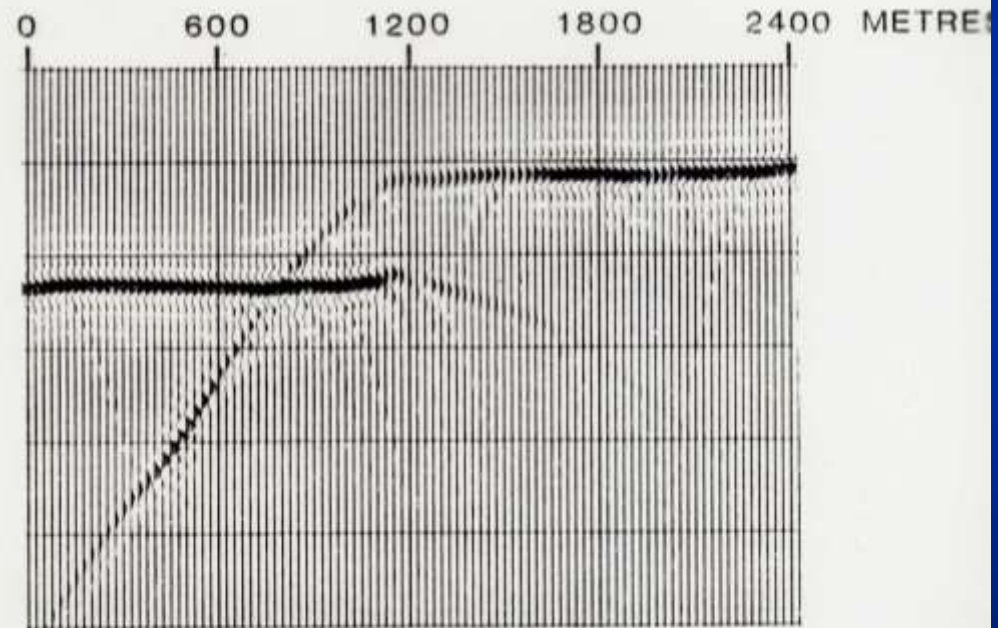


Stack Section

Time or Depth Migration ?

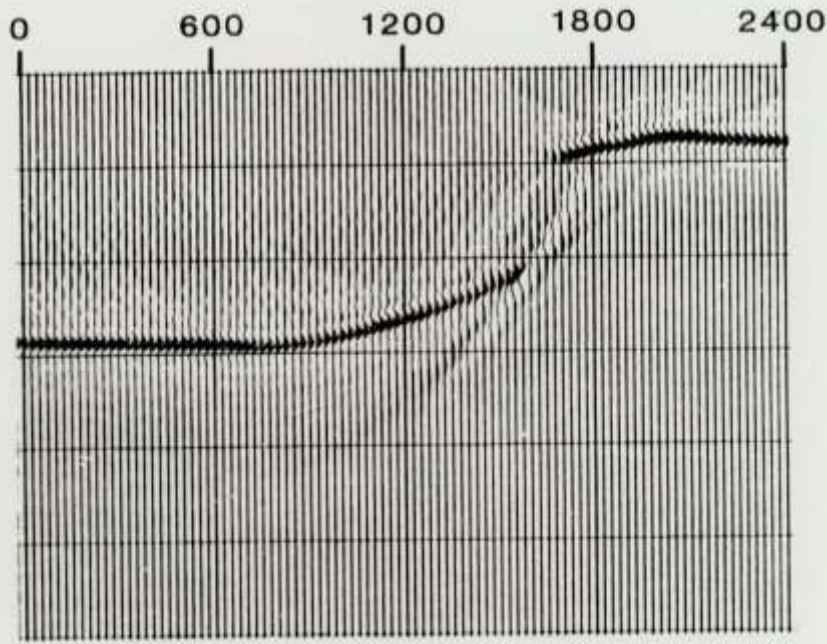


Stack Section

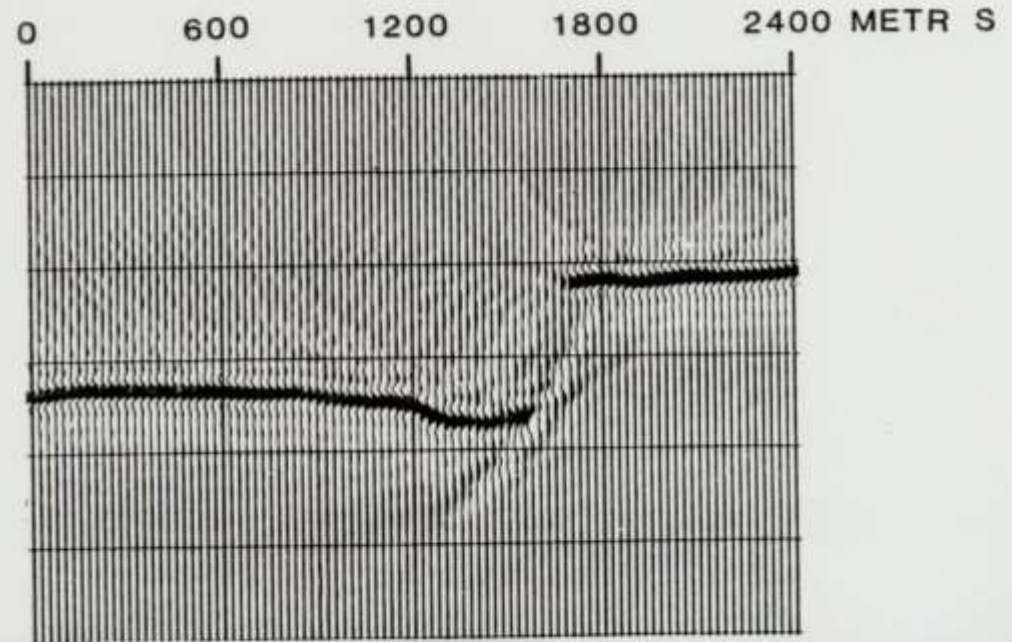


Depth Conversion of Stack Section

Time or Depth Migration ?

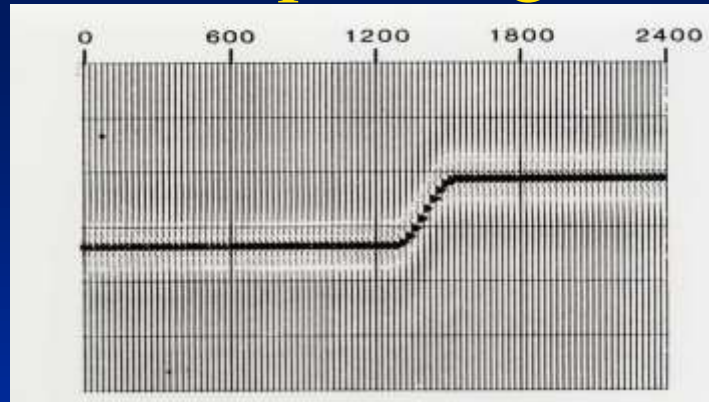


Time Migration

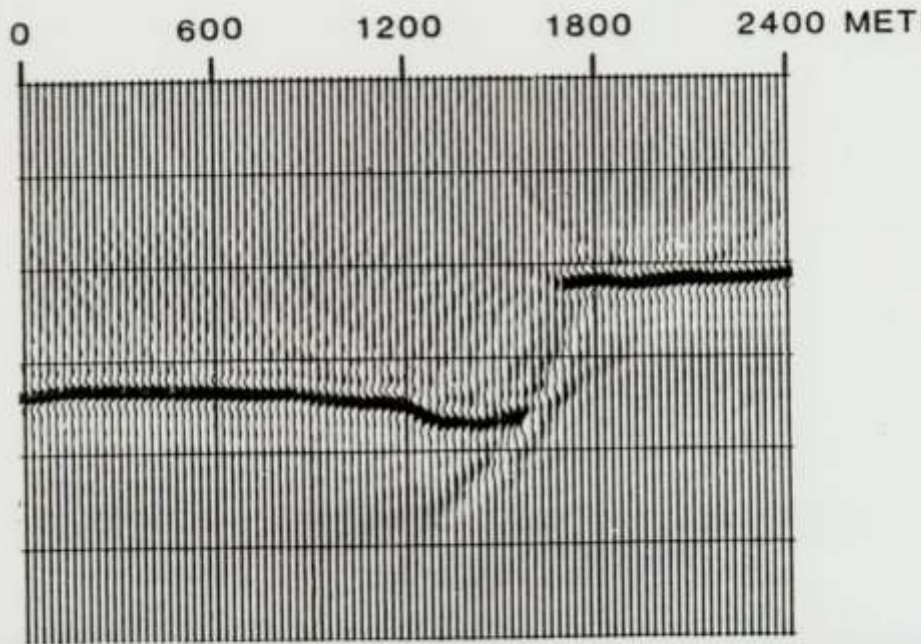


Depth Conversion Of Time Migration

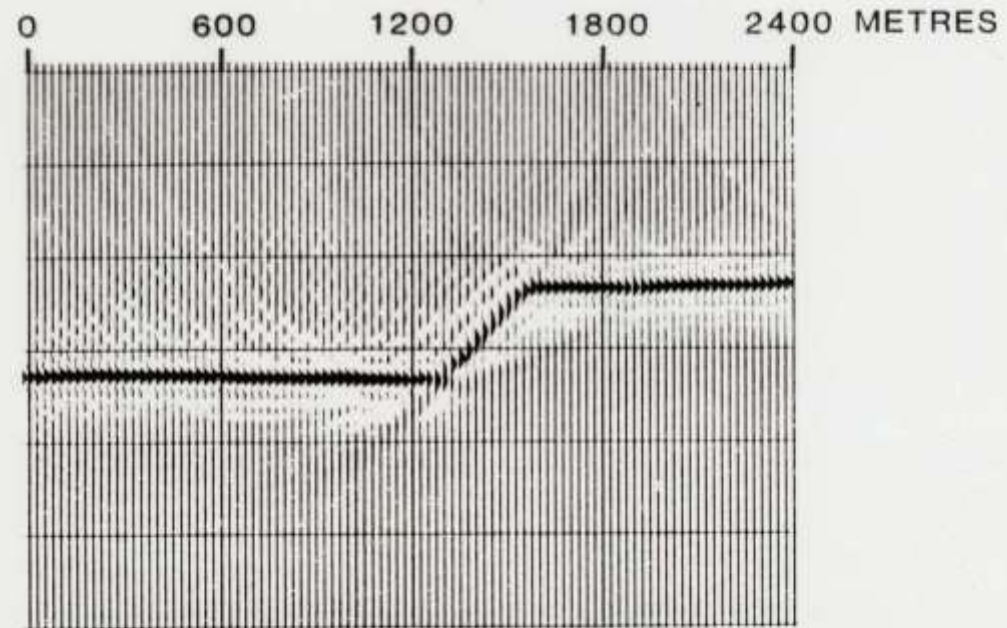
Time or Depth Migration ?



Model



Depth Conversion Of Time Migration



Full Depth Migration

Pre-stack or post-stack migration?



Pre Stack Migration

**Pre-Stack Migration is performed on unstacked data
It can be performed in both Time and Depth domains**



Ability to correct for ray path distortions and uncommon reflection points in areas of complex structure and dip



Better quality Migrated stack result



Retention of AVO and phase change information



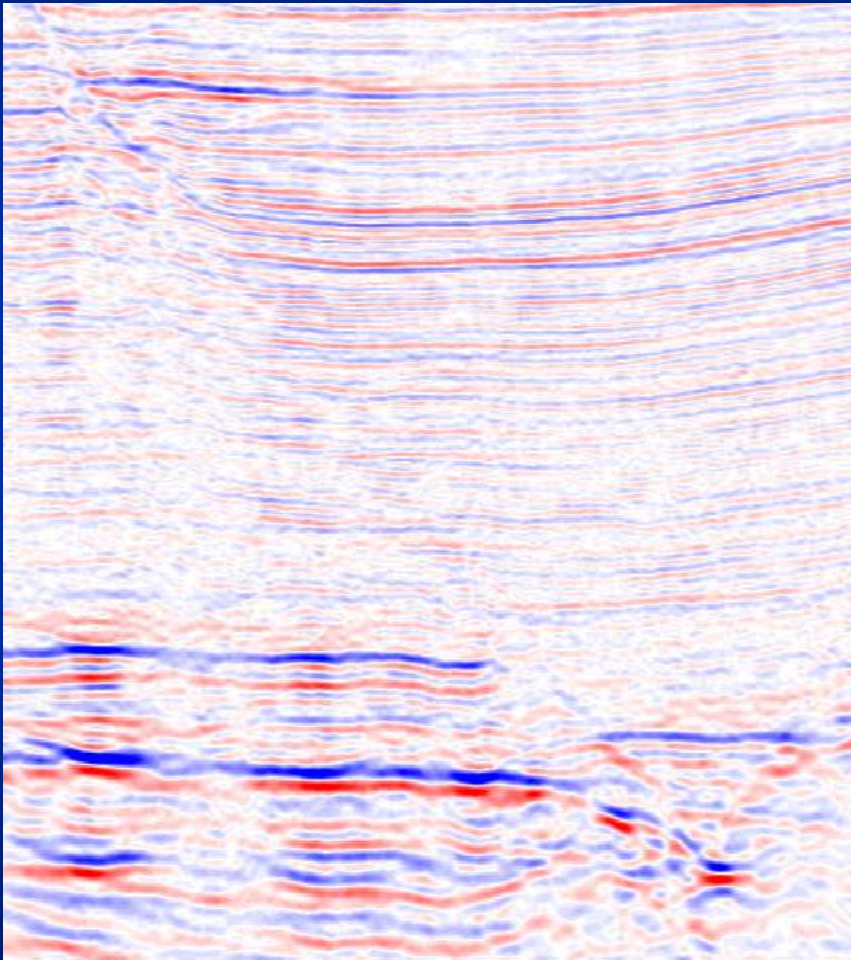
Lower S/N ratio



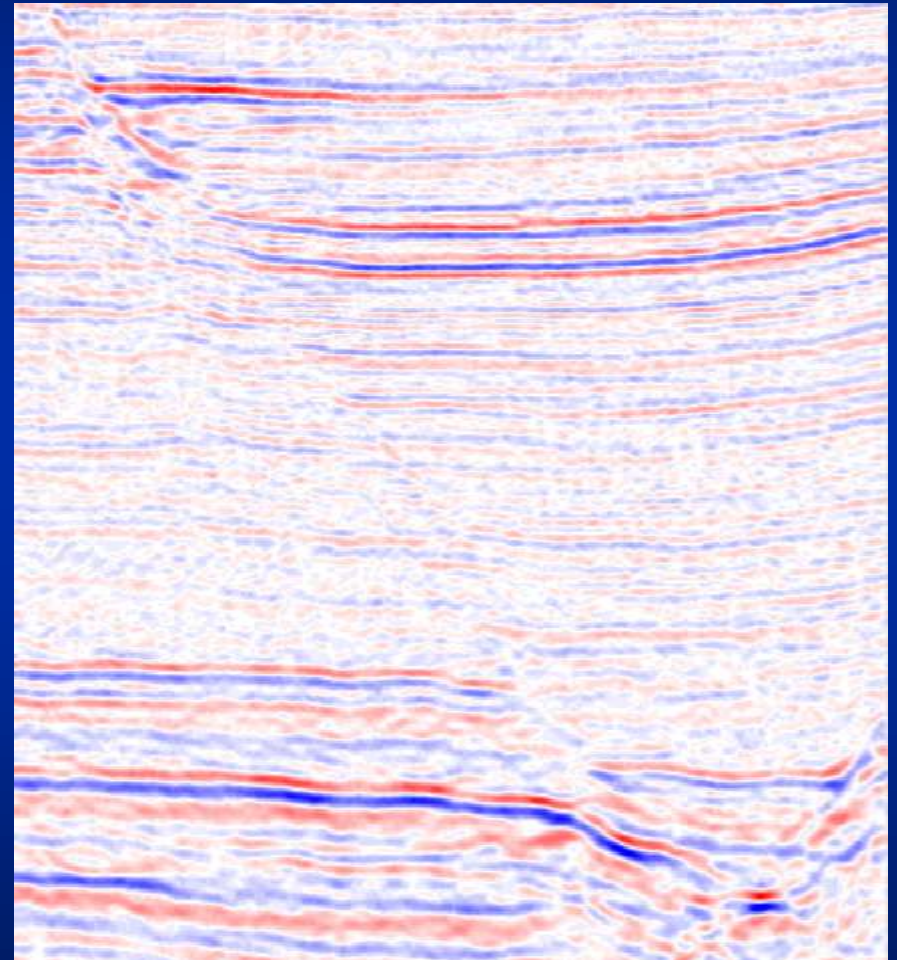
Cost

Pre-stack or Post-stack Migration ?

Post-stack depth migration



Pre-stack depth migration



At the end of this Session, you will be able to:

- Describe the important factors that influence the choice of migration type for a particular dataset.
- Describe and compare the advantages and disadvantages of the following migration methods: pre-stack, post-stack, time, depth, 2D and 3D.

Problems with Post Stack Time Migration



Time migration followed by depth conversion (as shown earlier) will not produce accurate imaging in the presence of steep dips and severe lateral velocity variations



Poor quality imaging from time migration



Time migration equations describe wavefield propagation through a horizontally layered medium



SOLUTION ?

Dip-Moveout Correction (DMO)

The CMP stack is an approximation to the zero-offset case - based on NMO correction -

$$t_x^2 = t_0^2 + X^2 / V^2$$

But for dipping layers, correction should be -

$$t_x^2 = t_0^2 + X^2 \cos^2 \theta / V^2$$

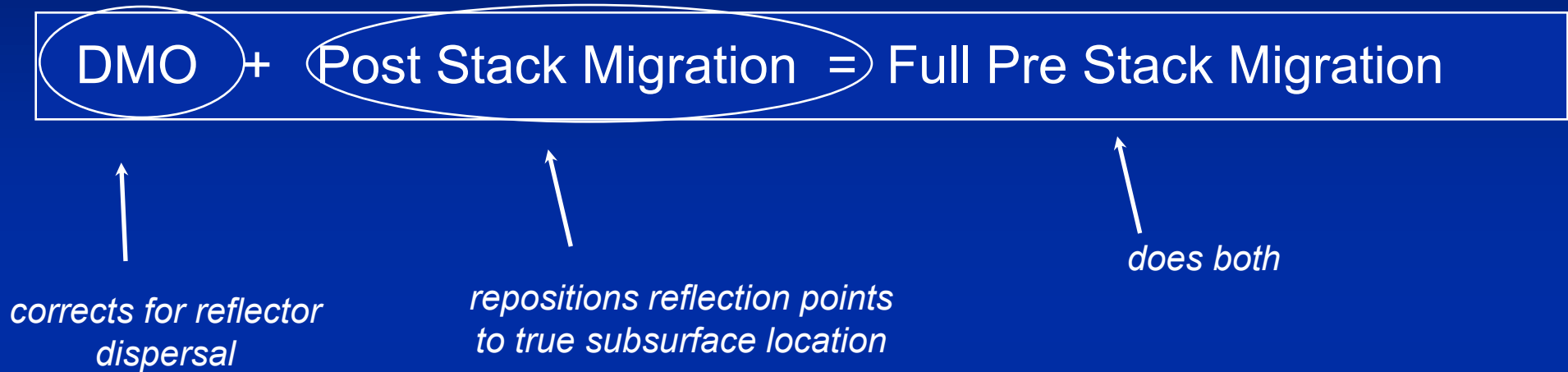
Or

$$t_x^2 = t_0^2 + \underbrace{X^2 / V^2}_{\text{NMO term}} - \underbrace{X^2 \sin^2 \theta / V^2}_{\text{DMO term}}$$

NMO term

DMO term

DMO - A Pre-Stack Partial Migration



DMO allows post-stack time migration to become equivalent to pre-stack time migration.

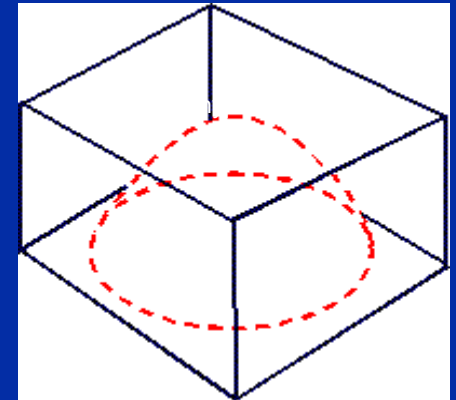
Migration of 3D Data

2D Migration



Only energy reflected in the plane of the section is correctly imaged

3D Migration

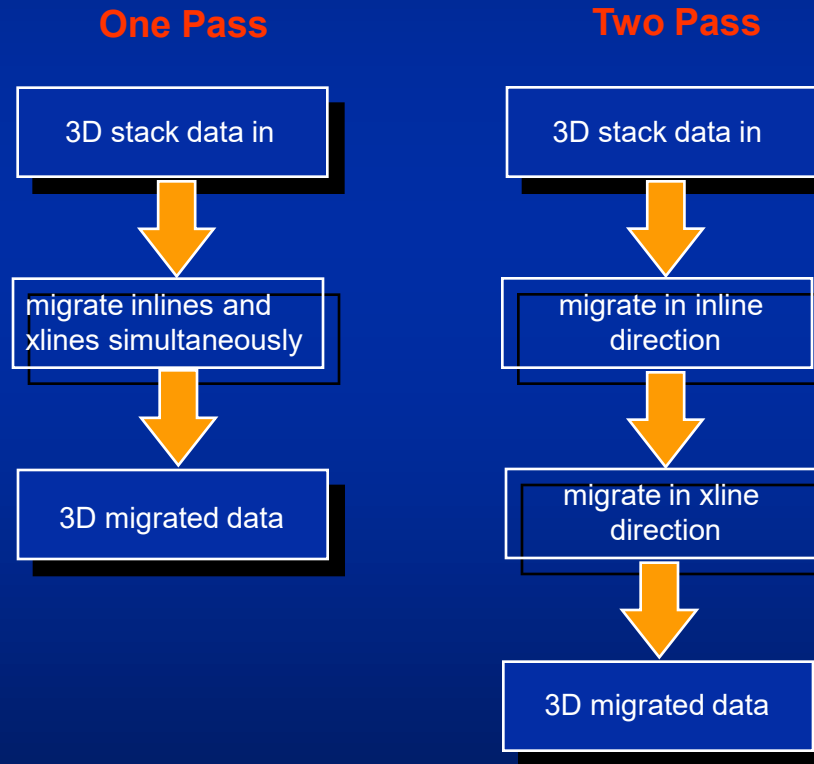


uses energy from both in and out of the plane of the section

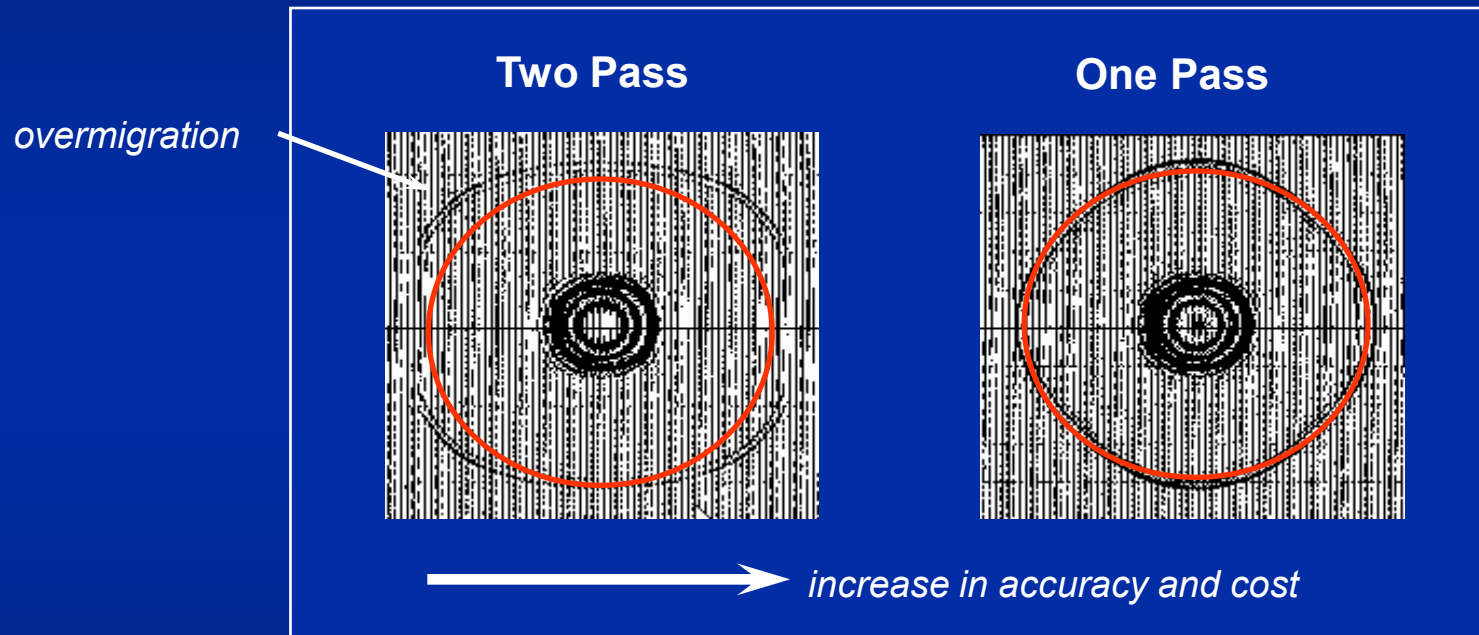
3D Migration will have a higher resolution as it can move energy from outside the plane back to its correct position

One pass versus Two pass

Migration of 3D data can be performed in one or two passes



One pass versus Two pass



When limited velocity variation

Two pass is a good match for One pass 3D migration

One pass versus Two pass

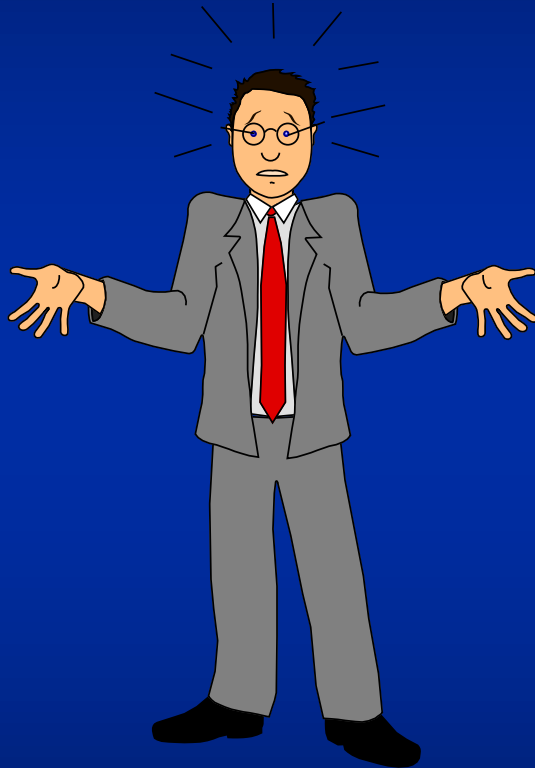
Two Pass

-  Simple to implement with existing algorithms
-  efficient use of resources
-  allows for use of two different algorithms
-  allows extra QC step
-  restricted to time migration
-  tends to overmigrate for realistic velocity models

One Pass

-  variation in velocities more accurately handled
-  both time and depth migration are possible
-  increased resources
 - 
 - use of omega-x migration algorithm - each frequency can be processed separately*

Which Migration to use?



Time or Depth?

Pre-Stack or Post Stack?

2D or 3D?

Algorithm?

Which Migration To Use?

Type	Pluses	Minuses
Pre stack	Migrated data is used to pick velocity analysis.	Higher cost than post stack. Low S/N.
Post stack	High S/N ratio. Lower cost than pre-stack	Assumptions in stack process breakdown when dip and velocity variation.
Time	Good result if velocity and dip variation not too complex - at an affordable price	Algorithms do not take account of ray bending - poor when large dip and velocity variations.
Depth	Algorithms take account of ray bending.	Requires very accurate velocity-depth model. Time and cost increase.
2D	Two pass on 3D data allows for use of different algorithms, extra QC.	Only uses energy from plane of section
3D	Uses energy from in and out of plane of section.	Resource/cost issues

Which Migration To Use?

What does the choice of migration type depend on ?

- **type of data**
2D or 3D
- **cost**
pre or post stack, algorithm
- **data characteristics**
S/N ratio, maximum dip, lateral velocity variation, algorithm
- **client objectives**
zone of interest, resources, own ideas

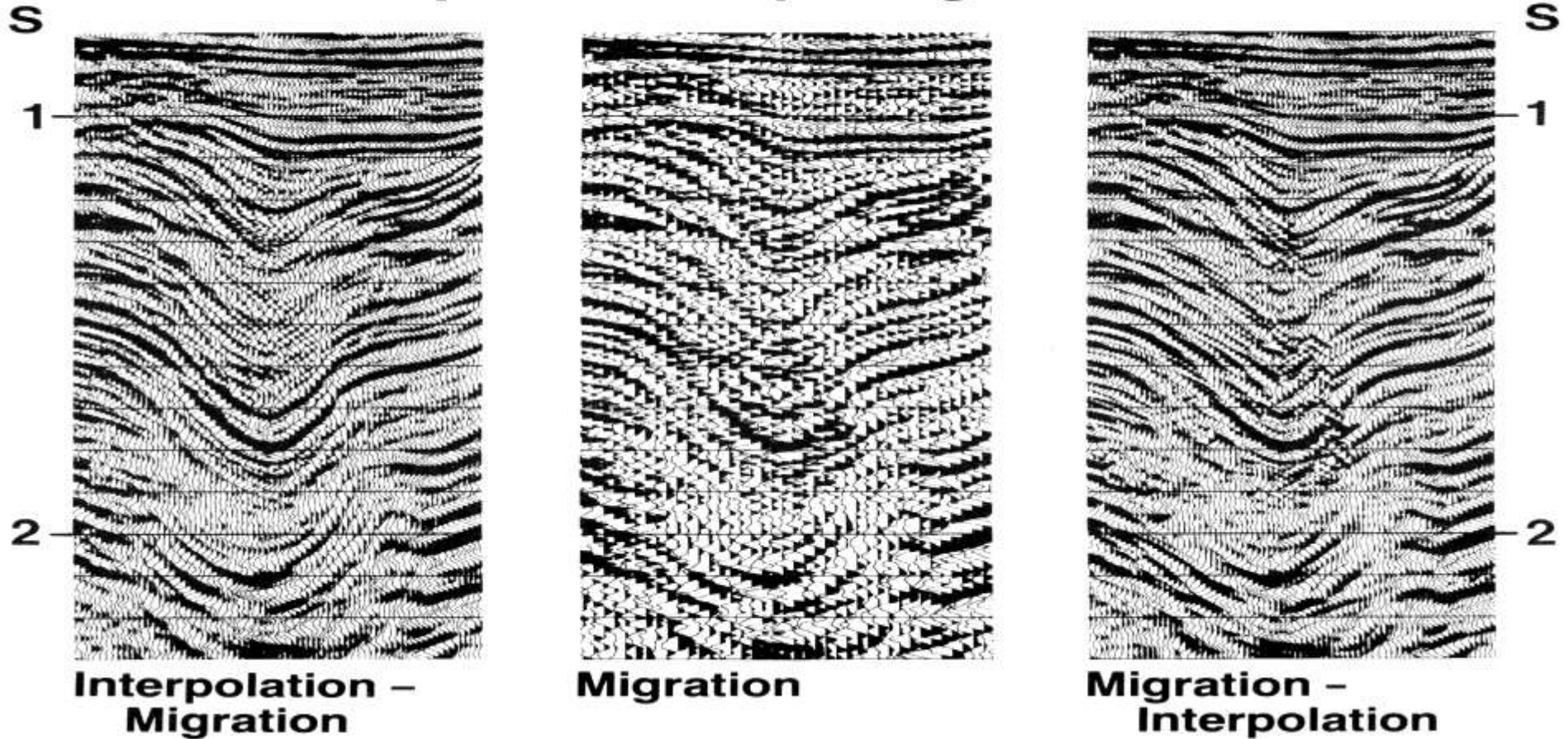
Factors Affecting Migration

Some additional factors that affect migration quality

- **Noise** - mainly coherent noise
- **Spatial Sampling** - in the presence of steep dips, aliasing can be a problem
- **Migration Aperture** - related to horizontal displacement of the reflection point
- **Amplitude Anomalies** - spikes, noise bursts, truncated traces etc.

Example of aliasing

Input Trace Spacing = 67m



What velocities do we use for migration ?

- **Post-stack time migration**

stacking velocity field may be smoothed and scaled

- **Pre-stack time migration**

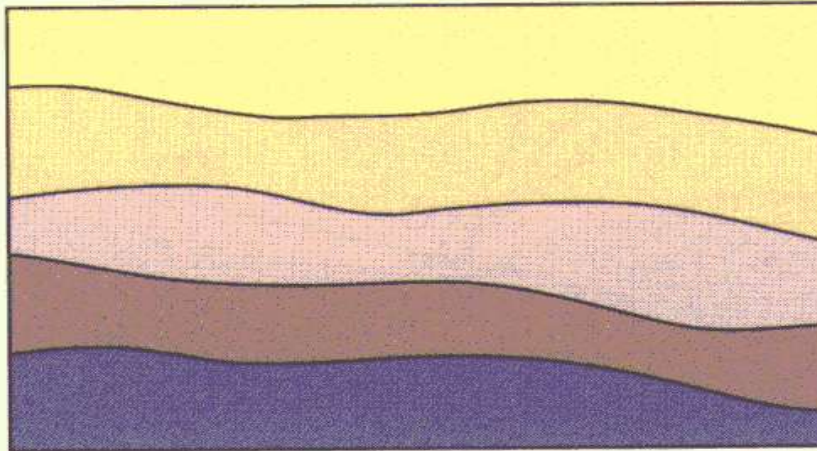
partial migration based on constant velocity (approx. 2000-3000m/s)
performed on common-offset gathers. The data is then
demigrated and velocities are re-picked

- **Depth migration**

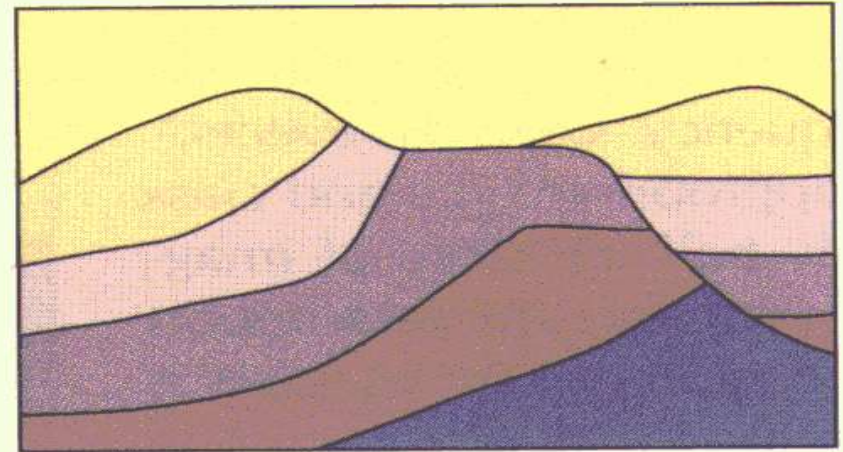
requires highly accurate velocity-depth model

Summary

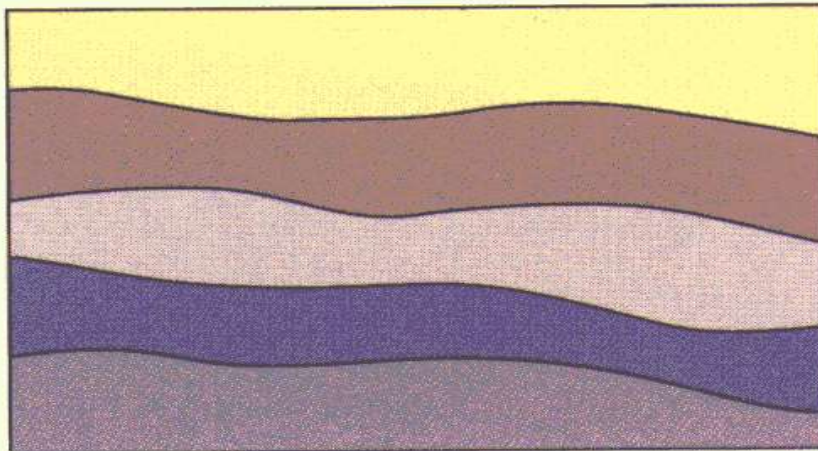
Simple velocities + simple structure = poststack time migration



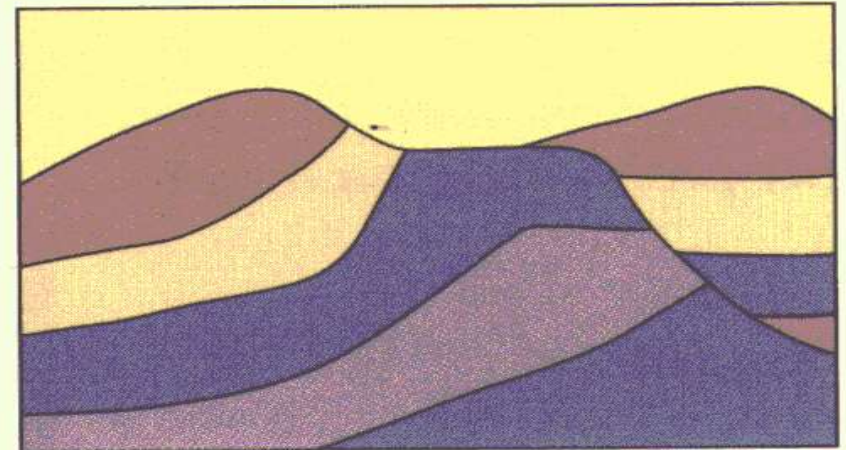
Simple velocities + complex structure = prestack time migration



Complex velocities + simple structure = poststack depth migration



Complex velocities + complex structure = prestack depth migration



At the end of this Session, you will be able to:

- Define the term 'migration' and describe why we need to migrate seismic data.
- Define the term 'diffraction energy'.
- Describe how the application of migration can affect dipping events and diffraction energy.
- To introduce the importance of the velocity field in the process of migration.
- Define the terms 'under migration' and 'over migration' in relation to a migration velocity field.
- Describe at least 3 ways in which a stacking velocity field may be manipulated to improve its suitability for the post-stack migration.
- Describe at least 2 reasons why scaling of stacking velocity fields may be required prior to their use in migration.
- Define the term 'migration smile'.

At the end of this Session, you will be able to:

- Define the 'imaging principle' and describe how it is related to the concept of 'exploding reflectors'.
- Define the principle of 'downward continuation' and describe how it is used in the migration process.
- Define the term 'migration algorithm'.
- Define the 3 main categories of migration technique namely, 'Finite-Difference', 'Integral' and 'Transform' methods and
- Name at least 4 algorithms based on these techniques.

At the end of this Session, you will be able to:

- Define the terms 'pre-stack migration' and 'post-stack migration'.
- Define the terms 'time migration' and 'depth migration'.
- Define the term 'depth conversion' and describe how it is different from depth migration.
- Describe the important factors that influence the choice of migration type for a particular dataset.
- Describe and compare the advantages and disadvantages of the following migration methods: pre-stack, post-stack, time, depth, 2D and 3D.